RODRIGO DE MIRANDA MONTEIRO SANTOS

HIERARCHY OF INTERPERSONAL SYNERGIES IN BASKETBALL: A THEORETICAL AND METHODOLOGICAL APPROACH

Tese apresentada à Universidade Federal de Viçosa, como parte das exigências do Programa de Pós-Graduação em Educação Física, para obtenção do título de *Doctor Scientiae*.

Orientador: Miguel Araújo Carneiro Júnior

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Miguel Araújo Carneiro Júnior
Orientador

DEDICATÓRIA

Dedico o presente trabalho àqueles "que têm a incerteza como sua disciplina, e que julgam que entender como agir sob condições de informação incompleta é a maior e mais urgente busca do ser humano".

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"Science can purify religion from error and superstition. Religion can purify science from idolatry and false absolutes."

(Pope John Paul II)

RESUMO

SANTOS, Rodrigo de Miranda Monteiro, D.Sc., Universidade Federal de Viçosa, dezembro de 2022. **Hierarquia de sinergias interpessoais no basquetebol: uma abordagem teórico-metodológica.** Orientador: Miguel Araújo Carneiro Júnior.

O objetivo desse estudo foi discutir e identificar, teórica e metodologicamente, os níveis hierárquicos (i.e., diádico e coletivo) de sinergias interpessoais defensivas no basquetebol. Foi sugerido que as características de uma tarefa restringem a formação de sinergias, do nível diádico ao coletivo. Consequentemente, identificar sinergias interpessoais multiníveis em esportes coletivos requer o estudo da formação de sinergias como um fenômeno contexto-dependente. Da mesma forma, recomenda-se que estudos futuros abordem essa questão e levem em consideração a relevância dos objetivos de performance em cada nível (i.e., diádico e coletivo) de análise. O conceito *Uncontrolled Manifold* (UCM) foi utilizado para determinar os limites de variabilidade dos valores dos elementos de tarefa que permitem a estabilização da medida de desempenho. Os elementos de tarefa foram as posições dos jogadores obtidas pelas coordenadas posicionais (x e y). O objetivo de performance selecionado para identificar a presença de sinergias interpessoais na fase defensiva ao nível diádico foi a distância interpessoal entre defensores, que, assume-se, tende a ser estabilizado para prevenir que um adversário se aproxime da cesta. Ao nível coletivo, o objetivo de performance selecionado foi a distância entre o centroide da equipe – formado pela posição média de todos os jogadores da equipe na quadra – e a bola, cuja estabilização é susceptível de assegurar coesão na defesa. As medidas propostas no presente estudo foram adequadas para descrever o comportamento sinergístico defensivo de uma equipe de basquetebol em uma partida da temporada regular da NBA, tanto ao nível diádico quanto coletivo. Sinergias diádicas baseadas na estabilização da distância interpessoal por dois defensores foram observadas durante toda a partida. Apesar de as sinergias coletivas terem sido observadas em apenas 30% das jogadas, a frequência das sinergias coletivas baseadas na distância entre o centroide da equipe e a bola pode estar relacionada à ocorrência de comportamentos defensivos mais complexos da equipe. Nenhuma diferença significativa foi encontrada na frequência ou força das sinergias entre duas equipes durante uma partida da NBA. As sinergias diádicas que mais contribuíram para a formação de sinergias coletivas (D5 e D6, respectivamente) foi o único aspecto que distinguiu significativamente o comportamento defensivo da Equipe A e da Equipe B. Todavia, as variáveis propostas nesse estudo foram capazes de identificar uma quantidade razoável de sinergias em ambos os níveis (i.e., diádico e coletivo). Mesmo assim, pesquisas adicionais são necessárias para investigar outras variáveis de performance e sua associação com o desempenho defensivo.

Palavras-Chave: Basquetebol. Sinergias. Uncontrolled Manifold.

ABSTRACT

SANTOS, Rodrigo de Miranda Monteiro, D.Sc., Universidade Federal de Viçosa, December 2022. **Hierarchy of interpersonal synergies in basketball: a theoretical and methodological approach.** Adviser: Miguel Araújo Carneiro Júnior.

The aim of this study was to discuss and identify, theoretically and methodologically, the hierarchical levels (i.e., dyadic and collective) of defensive interpersonal synergies in basketball. We suggest that the characteristics of a task constrain the formation of synergies from the dyadic to the collective level. Consequently, identifying multi-level interpersonal synergies in team sports demands studying the formation of synergies as a task-dependent phenomenon. Likewise, we recommend that future studies address this issue and take into account the relevance of performance goals in each level (i.e., dyadic and collective) of analysis. The Uncontrolled Manifold (UCM) concept was used to determine the limits of variability of values of task elements that allow to stabilize the performance measure. The task elements were players' positions captured by the bidimensional (x and y) coordinates. The performance goal selected for identifying the presence of interpersonal synergies in the defensive phase of play at the dyadic level was the interpersonal distance between defenders, which, it is assumed, tends to be stabilized to prevent an opponent to get near the basket. At the collective level, the performance goal selected was the distance between the team centroid – formed by the average positions of all players in the court – and the ball, whose stabilization is likely to ensure cohesion in defense. The measures proposed in the present study were adequate to describe the defensive synergistic behavior of a basketball team in a match of the regular season of the NBA, both at dyadic and collective levels. Dyadic synergies predicated on the stabilization of the interpersonal distance by two defenders were observed during the whole match. Although collective synergies were only observed in 30% of the plays, the frequency of synergies predicated on the distance between the team centroid and the ball might be related with the occurrence of more complex team defensive behaviors. No significant differences were found in the frequency or strength of synergies between two teams during an NBA match. The dyadic synergies that most contributed to the formation of collective synergies (D5 and D6, respectively) was the only aspect that significantly distinguished the defensive behavior of Team A and Team B. Nevertheless, the variables proposed in this study were capable of identifying a fair number of interpersonal synergies at both levels (i.e., dyadic and collective). Even so, further research is needed to investigate other performance variables and their association with defensive performance.

Keywords: Basketball. Synergies. Uncontrolled Manifold.

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GENERAL INTRODUCTION

The complex and dynamic nature of team sports brought the need to employ theoretical assumptions and methods that allow to explain the behavior of sports teams from the perspective of the interrelations between players and their role in the formation and conservation of collective organization (DAVIDS; ARAÚJO; SHUTTLEWORTH, 2005; MCGARRY et al., 2002). In this regard, the current Sports Science literature has employed concepts that enable the analysis of sports teams as complex adaptive systems, by investigating the formation of context-dependent structures called *synergies*, in which two or more elements act like a single entity (LATASH, 2008).

Synergies and Human Motor Behavior

Action is the only way through which human beings can work and interact with their environment. Indeed, the environment itself is responsible for constraining human acts, since we move in response to changing environmental landscapes (KELSO, 1982). Motor responses to environmental constraints are subject to processes of organization and control by the central nervous system (CNS), so that movements are coordinated and adequately performed according to the individual's purpose within the environment. Importantly, human action entails stabilization by a large number of kinematic chains, in order to properly organize and control this movement. This stabilization, in its turn, is one of the major functions of *synergies*. The concept of synergy was most prominently employed by Bernstein (1967), to describe a reduction in the number of motor degrees of freedom (DoF) to make the kinematic chains that give rise to human actions controllable. However, the synergy concept is not limited to describe the reduction of DoF for the control of kinematic chains. In truth, it has been argued that synergies are responsible for ensuring the stability of any kind of actions, even of the ones that do not necessarily include multi-joint kinematics (LATASH, 2021). According to this claim, what the CNS stabilizes are the properties related to a performance goal through adjustments in elemental variables (i.e., task elements), thus allowing synergies to be regarded as the "building blocks" of human motor coordination (LATASH; SCHOLZ; SCHÖNER, 2007).

Synergies, therefore, are responsible for the controlled stability of task-specific performance variables (LATASH, 2021). As a result, the formation of synergies is highly dependent on environmental features, rather than on the number or type of kinematic joints involved in the motor action. Also, different synergies (i.e., distinct assembles of motor units) may perform the same task, as specified by the degeneracy property (EDELMAN; GALLY, 2001). Accordingly, the description of the task(s) being performed is paramount for capturing motor synergies, since it will enable a more thorough identification of the relevant elemental variables (i.e., task elements) and performance goals (KIMMEL, 2021). This may be even more important at the *interpersonal* level of analysis, due to the complexity of the tasks involving two or more individuals, as well as of the increased number of possible motor solutions to the task. In order to build coordination at the interpersonal level, synergies between individuals are formed based on the property of *reciprocal compensation*, which enables individuals to react to the movement variations of other subjects (RILEY et al., 2011). The property of reciprocal compensation is central for the assumption that movement coordination emerges from the stabilization of the values of a performance variable, which, in its turn, is key to the *Uncontrolled Manifold* concept (SCHOLZ; SCHÖNER, 1999).

Synergies and the Uncontrolled Manifold Concept

The concept of *Uncontrolled Manifold* (UCM) has the purpose of justifying that motor coordination results from the relation between relevant system elements that reciprocally adjust to stabilize a performance measure (e.g., interpersonal distance) (SCHOLZ; SCHÖNER, 1999). This adjustment includes movements that are left free (i.e., uncontrolled), as they contribute to the stabilization of the performance measure, while other movements have to be controlled, since, otherwise, will perturb the stabilization of the performance measure, thus not contributing to the formation of a synergy. The aim of the UCM is to characterize the structure of variance of "uncontrolled" and "controlled" movements of task elements. Therefore, it is possible to refer to two kinds of variances: the compensated (i.e., associated to movement left free) and uncompensated variance (associated to movements that need to be controlled) (BLACK; RILEY; MCCORD, 2007). Thus, the compensated variance refers to adjustments in task elements, with the purpose of stabilizing the performance measure, whereas the uncompensated variance refers to the variations that interfere in the stability of the performance measure (SCHÖNER; SCHOLZ, 2007). The quotient between compensated and uncompensated variances enables to verify the presence and strength of interpersonal synergies (LATASH, 2010).

Furthermore, systems composed of a number equal to or greater than two elements are characterized by their hierarchical structural organization, as has been suggested in other studies (BALAGUÉ et al., 2019; POL et al., 2020; SANTOS; PASSOS, 2021). Consequently, due to the specific dynamics of sports teams, the identification of the hierarchical organization relative to interpersonal synergies is necessary, since it may provide essential information regarding the dominance of certain scales of observation over others, as well as the specifics of the situations in which this dominance is generated (GORNIAK; ZATSIORSKY; LATASH, 2007a).

Synergies and Team Sports

When addressed in the context of team sports, the topic of synergies has been limited either to the investigation of the intrapersonal scale (ROBALO et al., 2021) or, when approached at the interpersonal scale, to the analysis of lower levels, i.e., dyadic or group (PASSOS et al., 2020; PASSOS; MILHO; BUTTON, 2018). In team sports, dyads comprise the basic unit for analyzing synergistic behavior at the interpersonal level. A dyad is described as an assembly between two players with a common performance goal (MCGARRY et al., 2002; SCHMIDT; CARELLO; TURVEY, 1990). In their turn, group synergies refer to interactions between a number of players higher than two, although lower than the number of players that comprise the whole team, such as a defensive unit in soccer (PASSOS; DAVIDS, 2015). Finally, collective synergies are assemblies that presuppose that all the players within a team compensate the movement variations of their teammates, with the purpose of stabilizing a given performance variable (ARAÚJO et al., 2015). In one of the few studies that aimed to investigate the formation of interpersonal synergies at the collective level (DUARTE et al., 2013), by employing nonlinear analysis methods that allowed to verify the magnitude and structure of synchronies (referred to as synergistic relations) between players and their teams, the authors did not used metrics that allowed to confirm the existence of reciprocal compensation, deemed essential to the formation of synergies (RILEY et al., 2011; TURVEY, 2007).

The formation of interpersonal synergies results from the reciprocal relation between relatively independent agents within a system (e.g., two teammates), with the purpose of achieving a mutual performance goal (e.g., regain possession of the ball; maintain an interpersonal distance that prevents an offensive action in a given space) (RILEY et al., 2011; TURVEY, 2007). However, although some papers have already approached – both theoretically and experimentally – the topic of interpersonal synergies in team sports (ARAÚJO; DAVIDS, 2016; PASSOS et al., 2020; PASSOS; MILHO; BUTTON, 2018), the interrelation between the hierarchical levels of the synergies (i.e., from dyads to collectives) seems to have been, for the time being, left aside. Nonetheless, a significant step in this direction has been taken by Gorniak et al. (2007a). The authors investigated the hypothesis that the central nervous system (CNS) is capable of organizing one-hand (i.e., between fingers) and two-hand synergies, in a task that involves the production of force through the utilization of two fingers of each of the hands. Findings indicated a significant decrease, or even an absence, of synergies between the two fingers within a hand when the task demanded participants to use both hands, whereas these synergies were present when the task involved the utilization of only one of the hands (GORNIAK; ZATSIORSKY; LATASH, 2007a). Therefore, it is possible to verify the limitation of the CNS to organize and maintain the strength of intrapersonal synergies at two distinct hierarchical levels.

Accordingly, it can be understood that, at least at the intrapersonal scale, the relations between the hierarchical levels of synergies have already been confirmed. Consequently, it is possible to assume that the different hierarchical levels of the synergies formed at the interpersonal scale are likely to display a similar behavior, since a substantial portion of the literature suggests that the same principles that govern intrapersonal coordination (i.e., connection between a motor system's degrees of freedom, thus resulting in the formation of synergies) apply to this phenomenon at the interpersonal level (RILEY et al., 2011). Hence, the behavior of sports teams, understood from the point of vantage of interpersonal synergies, needs to be more deeply investigated, so as to allow the identification of the parameters that control the relation between the different hierarchical levels of the synergies observed in team sports, by taking into account the property of reciprocal compensation (POL et al., 2020; RILEY et al., 2011; SANTOS et al., 2018).

Interpersonal Synergies in Team Sports: Methodological Issues

Likewise, to be able to carry out the analysis of the hierarchy of interpersonal synergies, it is necessary to employ systems that allow tracking the positions of the players and the ball. Hence, the recent developments of computational technology have provided sports organizations with access to a wide range of detailed data on the exact location of each player within the court. Correspondingly, since 2013, the National Basketball Association (NBA) has employed the SportVU, an optical tracking system mounted in the arenas of all teams within the league (SPORTVU, 2022). This system is composed of six cameras mounted on the top of the arenas, and generates data at 25 frames per second, or 25 Hz. The system provides data on players' bidimensional coordinates (i.e., x and y), as well as on the tridimensional coordinates (i.e., x, y and z) of the ball. These data allow the exploration of several aspects of the game, such as court space management, whose complex characteristics precluded its description by means of traditional statistical procedures (WINSTON; NESTLER; PELECHRINIS, 2022).

Nevertheless, in basketball, data acquired through this kind of optical tracking devices have been mostly used for the analysis of offensive aspects. Even so, the analyses of the offensive phase in basketball that resorted to positional data have, largely, being limited to the proposition of indicators derived from quantitative variables measured directly, such as shooting efficiency, assists, screens, among others (FRANKS et al., 2015). Thus, it is important to highlight the relevance of the defensive phase in team sports, with respect to the identification of synergistic behaviors. Indeed, Krause and Nelson (2019, p. 198) claim that “the synergy found in defensive team chemistry can offset the natural advantage held by offensive players; defenders must play together to survive and thrive with *team* defense”. Following this account, it is possible to assume that the identification of relevant performance measures to quantify synergies in basketball may benefit from the analysis of the defensive phase, due to the demand, during the aforementioned phase, for behaviors that, not infrequently, require that two or more players act as a single unit, so as to reduce the space available for the attacking team to approach the paint and the basket (SHEA, 2014). Notwithstanding, during the offensive phase, the purpose of attacking players is predicated on the frequent search for behaviors related to the destabilization of the defensive system, aiming to generate space for penetrations and shots, thus making it more difficult to propose performance measures that may be stabilized to capture synergies during the offensive process (METULINI; MANISERA; ZUCCOLOTTO, 2018).

Thus, in order to support the identification and description of the dynamics that govern the behavior of complex adaptive systems, as well as the reciprocal influence between each of their levels – within the interpersonal scale –, it is necessary to resort to theoretical assumptions and methodological approaches, in addition to appropriate instruments, that allow to conceive the defensive behavior of basketball teams as hierarchical structures, so as to enable understanding the parameters that engender the formation of synergies (SANTOS; PASSOS, 2021).

AIMS

GENERAL

To discuss and identify, theoretically and methodologically, the hierarchical levels (i.e., dyadic and collective) of defensive interpersonal synergies in basketball.

SPECIFIC

To present theoretical considerations that enable to conceive of interpersonal synergies in team sports as a context-dependent phenomenon, which possesses a multi-level and interdependent hierarchical organization.

To identify and characterize the hierarchical organization of defensive interpersonal synergies in a professional basketball team in an NBA regular season match.

To compare the frequency and strength of defensive interpersonal synergies at dyadic and collective levels between two professional basketball teams in an NBA regular season match.

STRUCTURE OF THE THESIS

This thesis is organized following the norms for presentation of dissertations and theses of the Universidade Federal de Viçosa, comprised of one published scientific paper, and two other non-submitted papers, all three presented in the submission format, except for the refences sections, whose content was included in a single section at the end of the document.

The first section is composed by a General Introduction, in which are described the introductory elements of the study, as well as the justifications, relevance and purposes.

Next, the scientific papers are presented: The first paper, “A Multi-Level Interdependent Hierarchy of Interpersonal Synergies in Team Sports: Theoretical Considerations”, aimed to provide theoretical considerations that support interpersonal synergies in team sports as task-specific coordinative structures with a multi-level interdependent hierarchical organization.

The second paper, “Identifying Multi-Level Interpersonal Synergies in the Course of a Basketball Match”, aimed to quantify the presence of multi-level (dyadic and collective) defensive interpersonal synergies in the course of a competitive basketball match.

The third paper, “Multi-Level Interpersonal Synergies in Basketball: Comparing Two Teams in an NBA Match”, aimed to compare the defensive interpersonal synergistic behavior of two teams during an NBA match, both at dyadic and collective levels.

Finally, a General Conclusion about the study was presented, based on the main findings and practical implications.

PAPER 1

A Multi-Level Interdependent Hierarchy of Interpersonal Synergies in Team Sports: Theoretical Considerations

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Keywords: interpersonal coupling, task-specificity, coordination, degeneracy, team sports.

Introduction

Most daily activities (e.g., dialoguing, road trafficking) entails constant coordination between humans. Interpersonal coordination may occur when people share similar goals (DAVIS; BROOKS; DIXON, 2016; SCHMIDT; RICHARDSON, 2008) and results from the haptic or visual perceptive coupling of relatively independent individuals (e.g., a figure skating duo, two competing tennis players), which temporarily form a single coherent unit, defined as a soft-assembled *interpersonal synergy* (BLACK; RILEY; MCCORD, 2007; RILEY et al., 2011). Synergies are the basic structures from which movement coordination emerges, as they provide individuals with proper means for dealing with complex behavior under countless circumstances (KELSO, 2021).

As in other movement systems, the identification of soft-assembled synergies in team sports is often grounded on two key properties: dimensional compression and reciprocal compensation (RILEY et al., 2011). Dimensional compression refers to the process through which the coupling of the previously independent degrees of freedom (DoF) (e.g., players) within a system are reduced to a smaller number, resulting in a low-dimensional functional unit (BINGHAM, 1988; RILEY et al., 2011). For instance, instead of describing the behavior of each individual element, it describes the behavior of a dyad composed by two coupled elements, which consequently decreases the DoF under analysis. In turn, reciprocal compensation describes the capacity of each player within a synergy to adjust their behavior (e.g., increase or decrease running velocity), to compensate the behavioral variability among teammates, in order to stabilize a performance variable (e.g., interpersonal distance) (ARAÚJO; DAVIDS, 2016; RILEY et al., 2011).

In team sports, conceptualized as complex adaptive systems, it has already been suggested that interpersonal synergies are formed through feedback loops from the environment to the players and vice versa (BALAGUÉ et al., 2019). This suggests the existence of nested synergies, where some synergies are formed ‘within’ others. A recent study investigating a cooperative dyadic slackline task displayed evidence of a nested organization between intrapersonal and interpersonal synergies, with the intrapersonal synergies at a lower level (i.e., formed within other higher-level synergies) of organization (MONTULL et al., 2021). Hence, attempts to identify interpersonal coordination patterns that account for performance outcomes should consider the specificities of (nested) synergy formation at the following levels of analysis: micro, dyadic level (e.g., among two teammates); meso, group level (e.g., intra-group) and; macro, collective level (e.g., intra-team) carried out through circular causality (DAVIDS, 2015; JUARRERO, 1999). Circular causality in dynamical systems was defined as a situation in which the cooperation among individual elements of a system influence the global system behavior, which, in turn, governs the behavior of these individual elements (KELSO, 1995). While the nested synergies concept implies a more fixed hierarchy, the idea of circular causality (not to be confused with hierarchy) suggests a more dynamic behavior of that hierarchy. For instance, in the course of a football match, sometimes synergies may be formed between two defenders (dyadic level) and influence the soft-assembling of synergies of an entire defensive sector, whereas at other times this meso-level of the defensive sector may influence how synergies between two defenders will be formed. That is why we suggest a 'multi-level interdependent hierarchy' in the soft-assembling of interpersonal synergies.

The interdependence among these functional levels entails that only dimensional compression and reciprocal compensation may not suffice to accurately account for the principles that govern the formation of interpersonal synergies in team sports. Literature has recently proposed that degeneracy, defined as "the ability of elements that are structurally different to perform the same function or yield the same output" (EDELMAN; GALLY, 2001, pp. 98), can also be a property of soft-assembled synergies (ARAÚJO; DAVIDS, 2016; GLAZIER; DAVIDS, 2009; POL et al., 2020). In sports, these elements can be described as individual players, dyads or even groups of players. Therefore, there are several elements which are able to perform the same task/function, for instance if a full back fails to prevent an opposing winger from progressing towards the penalty area, another player (e.g., a center back) may be capable of fulfilling his/her role. In this paper, we suggest that these features allow to infer that coordination dynamics in team sports is based on a task-specific interdependent hierarchical level of interpersonal synergies, which means that at every instant any of the three levels can 'lead' the coordination dynamics within a team sports match.

Despite the growing interest on this topic, only recently has literature raised awareness of the importance of investigating the formation of interpersonal synergies in sports as a task-specific phenomenon with some kind of hierarchy (BALAGUÉ et al., 2019; MONTULL et al., 2021; POL et al., 2020). Nevertheless, the recent introduction of this concept to sports science literature implies that some important theoretical and methodological gaps regarding the hierarchical organization of interpersonal synergies in team sports still need to be bridged. Therefore, the purpose of this opinion article is to provide some theoretical considerations that support interpersonal synergies in team sports as task-specific coordinative structures with a multi-level interdependent hierarchical organization.

A Multi-Level Interdependent Hierarchy of Synergies in Team Sports

In team sports, the ultimate purposes of a team during the course of match are to score points (or goals) and to prevent the opposition from scoring. These purposes induce teams to create scoring opportunities through coordinated movements, and to preserve defensive balance and organization (GRÉHAIGNE; GODBOUT; BOUTHIER, 1999). Consequently, acting in a coordinated and functional fashion enables players to deal with the continuously emerging goals (e.g., preventing an opponent from approaching a potentially risky area) that lead to scoring/avoiding points or goals (ARAÚJO et al., 2015).

The dynamics of team sports performance imply that whenever an interpersonal synergy is unable to deal with contextual demands a “non-functional” synergy is assembled. Coordination arises whenever a synergy is formed but it may not fit to the contextual demands, which will likely lead to performance decrements and/or unsuccessful outcomes. Therefore, players need to adapt to form new (and more functional) synergies, either to fulfil the ongoing task or in response to newly formed environmental constraints (KELSO, 2021; LATASH, 2008). Accordingly, a specific performance goal (e.g., reducing the space, to decrease the opportunities of action of an opponent in possession of the ball) can be attained by the assembly of interpersonal synergies at distinct levels, such as dyadic or group levels (e.g., four players within a defensive set) (BALAGUÉ et al., 2019). By enabling different players to perform the same role, degeneracy is an indispensable property to be accounted for in the analysis of synergistic behavior in team sports, since it allows reciprocal compensation and, consequently, dimensional compression (ARAÚJO; DAVIDS, 2016; HRISTOVSKI; BALAGUÉ, 2020). However, due to task constraints, players can switch roles from one moment to the next. Therefore, degeneracy plays an essential role in the interdependence among levels of hierarchical organization of synergies, since it helps uncovering how interpersonal couplings at different levels interact with and overlap each other (e.g., the same player can contribute simultaneously to a dyadic and to a group synergy) to achieve specific performance goals (MONTULL et al., 2021). Nevertheless, the question regarding which synergy level ‘leads’ the match dynamics remains unanswered.

Addressing such a complex issue requires summoning up the inherent principles of hierarchical synergic control, whether in multi-agent systems, such as team sports, or in less complex ones, such as human hands and fingers (LATASH; ZATSIORSKY, 2016). For example, after analyzing intrapersonal synergistic behavior in prehensile tasks, Gorniak and colleagues (2007a, 2007b) identified the presence of idiosyncratic behaviors among synergies at two distinct hierarchical levels (i.e., hands level and fingers level) for producing force. Specifically, the authors observed that during prehensile tasks using only one hand, stabilization of the total force was achieved through the formation of strong synergies at the fingers level. Conversely, in prehensile tasks in which participants were asked to use their two hands, comparably strong synergies were formed between both hands, yet not between the fingers (GORNIAK; ZATSIORSKY; LATASH, 2007a, 2007b). This suggests that the hands level (i.e., meso level) overlapped the fingers level (i.e., micro level) regarding synergy formation and strength at an intrapersonal scale. Thus, by hierarchical control we mean the existence (even if temporary) of a higher level, which constrains the behavior of elements at lower levels.

If interpersonal synergies conform to the same governing rules as those at the intrapersonal level (RILEY et al., 2011), the aforementioned findings could precipitate the idea that soft-assembled interpersonal synergies involving more players result in the weakening of lower level synergies with less players. For instance, a synergy formed between two center-backs 'disappears' due to a new intra-sectorial synergy, formed by the whole defensive set. Nevertheless, a more likely explanation for the example above is that the lower level synergy formed by the two center-backs does not 'disappear' but to keep the functionality, turns its focus to the stabilization of another performance variable, for instance from the interpersonal distance to the interpersonal angle, probably as a result of changes in task constraints (BALAGUÉ et al., 2019; FAJEN, 2005). In fact, changing task characteristics may lead to a reorganization of the hierarchical levels of a synergy, so that the levels with higher functionality to achieve a specific performance goal are prioritized. For instance, two players forming a dyadic (micro-level) synergy aiming to regain ball possession can subsequently give up on their initial task goal, yet preserving the synergy but now focusing on reestablishing the balance of the whole defensive sector – a meso-level synergy (BINGHAM, 1988).

Thus, it seems natural to infer that specific synergies are more effective in relation to certain performance variables when the number of coupled players lies within a specific range. For instance, achieving success in a pick-and-roll play in basketball demands the formation of a functional synergy specifically at the dyadic level (e.g., a forward, as the ball handler, and a center, as the screener) (HRISTOVSKI; BALAGUÉ, 2020). With new task definitions, some performance variables can become more relevant to synergy formation. Thus, it seems appropriate to suggest that the hierarchical organization of synergies is more closely related to these 'new' performance variables, than to the number of players involved *per se*. If so, it will be up to the task characteristics to determine the hierarchical organization of synergies. Due to the dynamics of players' interactive behavior, the relevance of performance goals may change during the course of a match, with consequences for synergy formation. Therefore, we hypothesized that the formation of functional (i.e., successful) interpersonal synergies in team sports is governed by a task-specific, multi-level interdependent hierarchy. To deal with this sort of hierarchy, degeneracy plays a relevant role. A system in which all the structurally different elements (i.e., players) are able to perform the same task (e.g., stabilize interpersonal distances or angles) are more likely to have the necessary conditions to adapt and achieve the same outcome by assembling synergies to successfully perform tasks at all levels.

Preliminary findings in soccer (association football), reported by Carrilho et al., (2020), revealed that synergies formed by different numbers of players generated distinct values of the performance variable (team synchronization). The authors investigated two opposing teams during a match, and compared synchronization values between different team configurations (i.e., groups of players), assuming these configurations as different synergistic levels. Although only initial humble steps have been taken in this direction, the current empirical evidence has thus far reinforced the essential role of degeneracy in addressing a multi-level interdependent hierarchy of interpersonal synergies in team sports.

Thus, we suggest that addressing the issue of a multi-level interdependent hierarchy of interpersonal synergies requires identifying the most relevant performance goals for the three levels of analysis (i.e., micro, meso and macro) and for every phase of play in a team sports match.

Discussion

The aim of this opinion article was to evoke key assumptions supporting the hypothesis of interpersonal synergies as a multi-level, interdependent, hierarchically organized phenomena, as well as to discuss their implications for studying multi-level synergistic behavior in team sports. Here we may suggest that task-specificity constrains the formation of synergies at all levels. Accordingly, identifying the hierarchical organization of interpersonal synergies in team sports entails the adoption of a perspective of synergy formation as a task-dependent phenomenon. However, what needs to be discussed is, how do task characteristics prioritize certain levels over others? Do stronger synergies constrain (overlap) weaker synergies, or are the levels defined by the number of elements that assemble a synergy? All these questions remain unanswered. Previous research in football (Carrilho et al., 2020) provided us with some thought-provoking queries, regarding the role played by performance goals in synergy formation and strength at each level, as mentioned throughout this paper. Therefore, we suggest that future attempts to address these questions should be equated with the relevance of the performance goals.

Finally, investigating the hierarchical organization of synergies in team sports, as well as the relationship among the distinct synergistic levels may help researchers and coaches in understanding, planning, practicing and assessing team performance, as well as the effectiveness of styles of play.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

RS and PP: article development and composition. PP: final draft review.

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PAPER 2

Identifying Multi-Level Interpersonal Synergies in the Course of a Basketball Match

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Identifying Multi-Level Interpersonal Synergies in the Course of a Basketball Match

In the team sport of basketball, players need to cooperate to form defensive synergies to prevent the attacking team from scoring. The purpose of this study was to quantify the presence of multi-level (dyadic and collective) defensive interpersonal synergies in the course of a competitive basketball match. The sample comprised a basketball match played during the 2015/2016 NBA regular season. The Uncontrolled Manifold concept was employed to identify those interpersonal synergies. For that purpose, the defenders' interpersonal distance and the distance between the defensive centroid and the ball were used as performance goals, whereas players' positions were used as task elements. The results identified the presence of dyadic and collective synergies throughout the entire match, although the latter were significantly less frequent. It is possible to conclude the existence of multi-level interpersonal synergies in the course of a basketball match.

Keywords: Interpersonal synergies; basketball; interpersonal distance; centroid.

Introduction

Human beings constantly work together to perform activities such as chatting, dancing, and playing sports. Therefore, the study of human interactive behavior is paramount to understand how people cooperate with each other in order to achieve a mutual goal (PASSOS; DAVIDS; CHOW, 2016). Accordingly, researchers have focused on the topic of interpersonal coordination with the purpose of uncovering the assumptions that govern human interactive behavior (NORDHAM; KELSO, 2016; SCHMIDT; RICHARDSON, 2008). However, the interaction between two (or more) people entails a large number of opportunities of action, assumed as degrees of freedom (DoF), which raised the question on how these agents control those seemingly independent DoF to achieve a common performance goal.

The interpersonal synergy concept advocates that DoF are coupled, generating a dimensional reduction due to individuals compensating for variance in each other's behavior, which consequently leads to the formation of an interpersonal synergy (BERNSTEIN, 1967; LATASH, 2021; RILEY et al., 2011). Hence, an interpersonal synergy is a structure that controls individual DoF in order to making its constituents (e.g., two players within a team) act like a single coherent unit (LATASH; SCHOLZ; SCHÖNER, 2007).

In team sports, players need to interact with teammates, thus rendering a prolific research avenue in interpersonal coordination (SANTOS et al., 2018). In terms of synergy formation, teams sports are characterized by the informational coupling between two (i.e., dyads) or more players (i.e., groups or collectives), who interact in order to contribute to a team performance goal (MCGARRY et al., 2002). Hence, analyzing different levels (e.g., dyadic and collective) of synergistic behavior can provide relevant information on the coordinative structures that characterize performance in team sports (SANTOS; PASSOS, 2021).

During the course of any competitive basketball match, players are constrained to form interpersonal synergies at different levels, avoiding the opposition from scoring points

(LAMES; MCGARRY, 2007; MCGARRY; PERL; LAMES, 2014). Particularly, the synergies formed between defenders at dyadic or collective level have the potential to neutralize the strengths of the attacking team through the formation of a coherent ensemble, in pursuit of a common goal (KRAUSE; NELSON, 2019). Consequently, employing appropriate metrics that allow to capture dyadic and collective couplings is paramount to determine the performance goals shared by the players to adjust their behaviors in basketball defense (BOURBOUSSON; SÈVE; MCGARRY, 2010b). For instance, at the dyadic level, defenders are requested to maintain a certain interpersonal distance preventing the creation of a threatening space between them that could be used by the attacking team. Thus, the candidate to a performance goal at dyadic level was the interpersonal distance between any two defenders (PASSOS et al., 2011). Both defenders should stabilize this metric, so as to avoid conceding space for opposing players to approach the basket (BEN ABDELKRIM; EL FAZAA; EL ATI, 2007; GANDOLFI, 2009). On the other hand, the candidate to a performance goal at collective level was the distance between the defensive centroid position in the court and the ball. Players positional adjustments seek to stabilize this performance goal, in order to prevent the attacking team from getting closer to the basket (SAMPAIO et al., 2014).

Nevertheless, although some studies have identified synergistic traits in team sports (PASSOS et al., 2020; PASSOS; MILHO; BUTTON, 2018; SILVA et al., 2016), the analysis of the presence of interpersonal synergies at different levels has not been addressed thus far (SANTOS; PASSOS, 2021). The study of multi-level interpersonal synergies in basketball has the potential to uncover the reciprocal actions between players that give rise to collective behavior, since it regards these informational couplings as indivisible units of analysis (RILEY et al., 2011). Therefore, resorting to this approach for describing interpersonal synergies in basketball might help identifying the “building blocks” of team coordination, by capturing reciprocal behaviors from the dyadic (i.e., player-player) to the collective (i.e., whole team) level (PASSOS et al., 2009). More importantly, a multi-level analysis of interpersonal synergies allows to unearth which – and how – mutual performance goals govern dyadic and collective couplings (SANTOS; PASSOS, 2021). Consequently, the utilization of metrics that correspond to a particular phase of play (i.e., defense), the specific behaviors that characterize the selected events can be accounted for, which acknowledges the importance of associating these appropriate metrics to their respective tactical goals (GARGANTA, 2009).

Thus, the purpose of this study is to identify defensive interpersonal synergies in a basketball team at dyadic and collective levels. We hypothesize that dyadic and collective defensive synergistic traits will be identified through the measures proposed here.

Materials and Methods

Data acquisition

The data correspond to a competitive basketball match played during the 2015/2016 NBA regular season. Over this match, the team under scope had 12 participating players. Positional *x* and *y* coordinates were obtained through an optical tracking system (STATS SportVU, Stats Perform) (SPORTVU, 2022) with six cameras – mounted in the arena – that capture in real time the positions of the ball and the players within the court, with a sampling rate of 25Hz. Data are publicly available at the GitHub repository (https://github.com/linouk23/NBA-Player-Movements). Data were processed and visualized using Python 3.10.4 (Python Software Foundation), with Matplotlib 3.5.2 and Pandas 1.4.2 modules. Data was reconstructed in 2D, and the events selected for analysis were checked using images from the TV broadcast of the match. The analysis carried out on this study did not require identification of individual performers.

Players' positional roles were used to identify the dyads, according to the following criterion: P1 (point guard); P2 (shooting guard); P3 (small forward); P4 (power forward); P5 (center). Consequently, dyads were classified according to all possible interactions between players from each position (BOURBOUSSON; SÈVE; MCGARRY, 2010b): D1 (P1/P2); D2 (P1/P3); D3 (P1/P4); D4 (P1/P5); D5 (P2/P3); D6 (P2/P4); D7 (P2/P5); D8 (P3/P4); D9 (P3/P5) and D10 (P4/P5).

Categoric Variables

The hierarchical levels of the synergies (i.e., dyadic and collective) were the categoric variables of this study.

Synergy Analyses

The Uncontrolled Manifold (UCM) concept will be used to determine the limits of variability of values of task elements that allow to stabilize the performance measure. The purpose of UCM is to uncover the structure of variance of organisms with several degrees of freedom, controlled by a single measure (PASSOS; MILHO; BUTTON, 2018; SCHÖNER; SCHOLZ, 2007). The hypothesis that the selected task elements are really capable of stabilizing performance goals and, as such, of identifying an essential property of synergies (i.e., reciprocal compensation) can be verified through the ratio between compensated and uncompensated variances (BLACK; RILEY; MCCORD, 2007; RILEY et al., 2011). The UCM was calculated in time for each play, in both levels of analysis (i.e., dyadic and collective), considering their respective performance goals and task elements. The variance along UCM values over time uncovers the reciprocal compensation regarding players' movements – measured by changes in x and y coordinates – that stabilize the performance goals in each level around a given reference value, while the perpendicular variance reveals changes that were not compensated for by players' movements (PASSOS et al., 2020).

To calculate the UCM over time for each play, the model was discretized using discrete time points based on players' x and y positional coordinates. The length of each play was considered as the period between resets of the shot clock, which means either the start of a new play by the same team or a turnover in ball possession.

The task elements were players' positions captured by the bidimensional (x and y) coordinates. The performance goal selected for identifying the presence of interpersonal synergies in the defensive phase of play at the dyadic level was the interpersonal distance between defenders, which, it is assumed, tends to be stabilized to prevent an opponent to get near the basket (BOURBOUSSON; SÈVE; MCGARRY, 2010b). At the collective level, the performance goal selected was the distance between the team centroid – formed by the average positions of all players in the court – and the ball, whose stabilization is likely to ensure cohesion in defense.

The UCM output is a ratio between the compensated and the uncompensated variance, which means that there are synergies for whenever UCM ≥ 1. However, there is no upper limit for the UCM, thus, in order to reduce skewness of the distribution, a log transformation ($\log_{10}$) was applied to UCM values. Hence, synergies were classified as such when logUCM ≥ 0. Accordingly, the higher the (positive) value of logUCM, the greater the strength of the synergy.

The UCM computation for synergy analyses was carried out using MatLab® 2022a (The MathWorks Inc., Natick, MA, USA).

Data Analysis

The One-Way ANOVA and t-test were used to compare logUCM values between dyadic and collective levels, throughout the match and within each half, respectively. The chi-squared (χ^2) test was used to verify differences in proportions regarding dyadic and collective synergies, throughout the match. Pearson's correlation (r) was used to verify the association between collective and dyadic synergies, in order to identify the dyads that significantly contribute to the formation of synergies at the team level. Explained variance (r^2) was calculated for significant correlations. Statistical procedures were carried out using SPSS, version 25. The significance level was set for $p < 0.05$.

Results

Multi-Level Synergies

Table 1 shows the mean values of logUCM, as well as the frequencies, of dyadic (D1 to D10) and collective (Centroid/Ball) synergies (logUCM ≥ 0).

Table 1. Means (standard deviations) of logUCM and absolute (relative) frequencies of dyadic and collective synergies.

	Dyads										Collective
	D1	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**	**Centroid**
logUCM	0.90(0.63)	0.90(0.55)	0.89(0.57)	0.83(0.51)	0.90(0.56)	0.82(0.55)	0.89(0.52)	0.88(0.58)	0.82(0.51)	0.74(0.50)	0.65(0.57)
Frequency	58(82%)	56(80%)	57(81%)	55(78%)	59(84%)	60(85%)	60(85%)	56(80%)	59(84%)	58(82%)	21(30%)*

*Significant difference ($p < 0.05$).

It is possible to note that dyadic synergies were formed in most plays, whereas the number of collective synergies was substantially lower. Indeed, dyadic synergies were significantly more frequent than the synergies formed at the collective level ($\chi^2 = 23.11$; $p = 0.010$). In contrast, One-Way ANOVA did not reveal any significant differences ($F = 0.739$; $p = 0.68$) in the mean logUCM values between dyadic and collective synergies.

Table 2 shows the values of Pearson's *r* for the correlations between collective and dyadic synergies (logUCM ≥ 0).

Table 2. Values of Pearson's correlation (*r*), significance and explained variance (r^2) between collective synergies (n = 21) and each dyad.

	D1	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
r	0.32	0.29	0.13	0.17	0.46	0.43	0.11	0.34	0.30	0.27
Sig.	0.15	0.19	0.57	0.46	0.03*	0.05	0.61	0.12	0.17	0.23
***r*²**	-	-	-	-	0.21	-	-	-	-	-

*Significant correlation ($p < 0.05$).

According to Table 2, only D5 (P2/P3) was (positively) correlated with synergies at the collective level. More specifically, the D5 dyad is likely to contribute approximately 21% ($r^2 = 0.21$) to the values of logUCM of collective synergies (formed between the defensive team centroid and the ball).

Synergy Formation

Figure 1 displays the collective synergies captured during the match, across both halves.

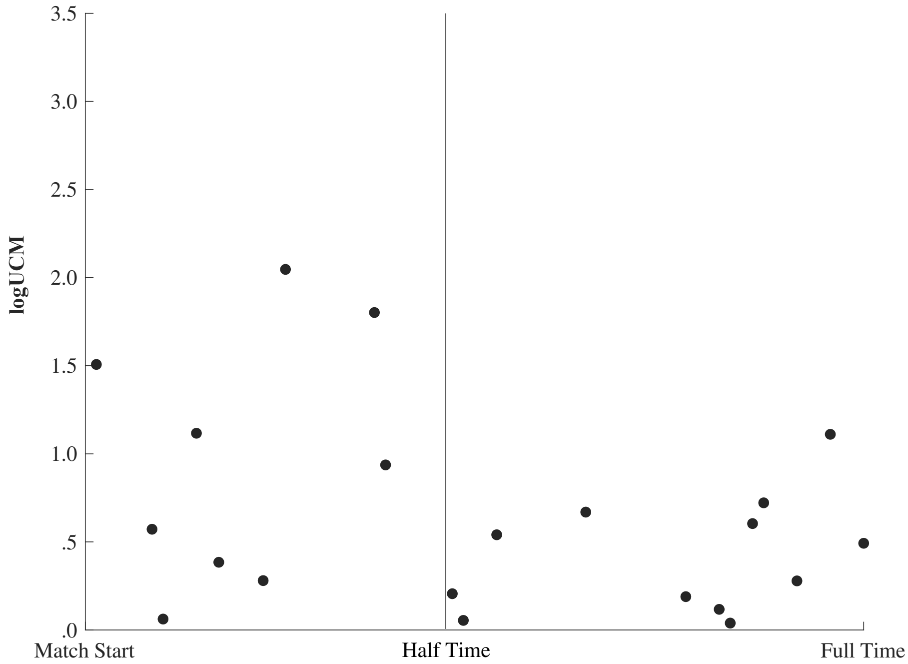

Figure 1. Collective synergies (logUCM ≥ 0) formed during the match.

The independent t-test revealed that significantly stronger collective synergies were formed during the first half of the match, in comparison to the second half ($t = 2.395$; $p = 0.027$), although collective synergies were more frequent in the second ($n = 12$) than in the first half ($n = 9$).

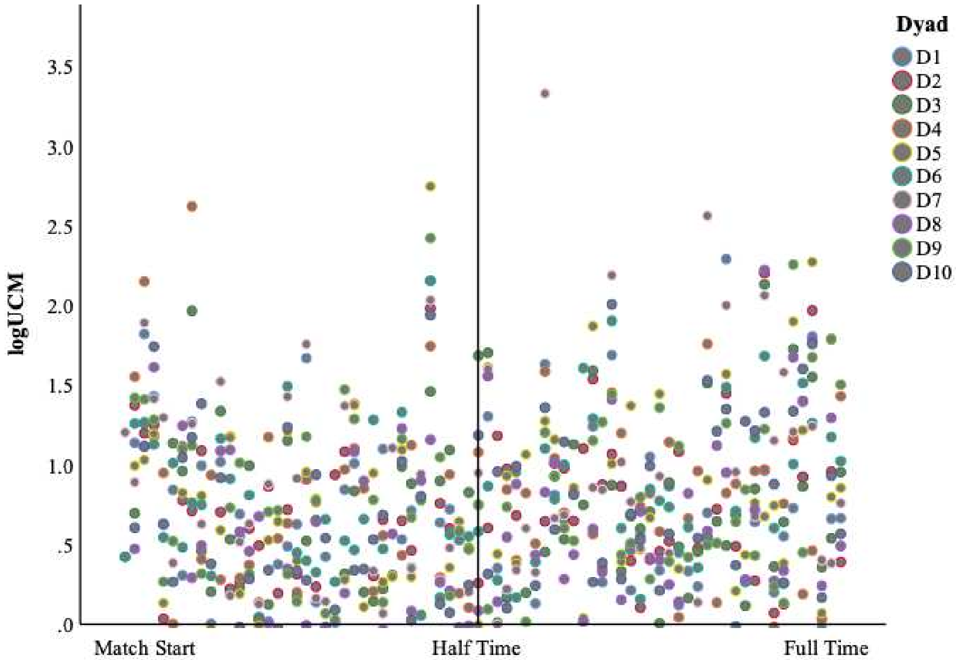

Figure 2. Dyadic synergies (logUCM ≥ 0) formed during the match.

Dyadic synergies were observed throughout the entire match. Also, by comparing both figures (Figure 1 and Figure 2), it is possible to observe that the number of dyadic synergies is noticeably higher than that of collective synergies. Finally, no significant differences were found on the frequency of synergies between the dyads, either throughout the match or within each half ($\chi^2 = 0.478$; $p = 0.999$ and $\chi^2 = 1.403$; $p = 0.998$, respectively). Also, the One-Way ANOVA did not reveal any significant differences in strength between the distinct dyads ($p = 0.867$).

Discussion

The purpose of this study was to identify defensive interpersonal synergies in a basketball team at dyadic and collective levels. Indeed, at the dyadic level, the analysis of the stabilization of interpersonal distance between players predicated on their positional variability revealed a substantial number of synergies. On the other hand, only a few collective synergies were observed through the analysis of the stabilization of the distance between the defensive centroid and the ball.

With respect to the formation of dyadic synergies, it is actually expected that in defense players frequently have to work with another teammate to generate numerical superiority in relation to the opponent with the ball, in order to reduce his/her space to dribble and decrease his/her chances of, for instance, performing a successful screen or getting into the paint and score (GÓMEZ et al., 2015). Consequently, double guarding the player in possession is a common strategy in professional basketball, particularly when the player in question possesses advanced dribbling skills (SHEA, 2014). To be sure, the results of the present study revealed that at least one dyad was formed in nearly all the plays.

The findings revealed that dyadic synergies were more frequent than collective synergies, which – as one could anticipate – possibly denotes that forming synergies at the collective level is a rather more complex task than the formation of dyadic synergies, since it entails that the same performance goal is shared by five different players, instead of only two, which indicates that a higher degree of reciprocal compensation is necessary to form synergies at the collective level (KRISHNAMOORTHY et al., 2003). Also, these results accord with the kind of mixed defense (i.e., individual + zone) commonly applied by NBA teams. In comparison with zone and individual defenses considered in isolation, mixed defense encompasses aspects from both methods, which means that teams frequently employ two players to guard the ball carrier, in order to reduce his/her chances of getting an open shot (LUCEY et al., 2014). Likewise, the different possible dyadic synergies seemed to be evenly distributed throughout the match, as no significant differences were found in the frequencies of the dyads between both halves. Therefore, it is possible to infer that identifying synergies predicated on the stabilization of defenders interpersonal distance can help analysts and coaches by providing insights on which pairs of players are coordinated during any given defensive play as well as on the strength of the synergies they are forming (BOURBOUSSON; SÈVE; MCGARRY, 2010b). This information may help uncovering teams' defensive characteristics, as it has the potential to reveal which couplings of players are more effective in guarding a given opponents with the ball, thus pinpointing specific strengths and weaknesses regarding dyadic defensive behavior. Nevertheless, it should be noted that the formation of dyadic synergies was not analyzed in relation to ball position, thus suggesting a limitation of the present study, which does not allow to infer that the observed dyads were formed by two players directly guarding the ball carrier. We recommend that future research on the defensive synergistic behavior of players in team sports address this issue.

As for the collective synergies identified through the analysis of the stabilized distance between the team centroid and the ball, it may be relevant to point out the need reported by authors in previous studies for finding reliable variables capable of describing collective behavior in team sports (SARMENTO et al., 2022; SATHYAN et al., 2012). By the same token, coming across measures that enable the identification of team synergies in sports competition is a complex endeavor, since it also entails the definition of stabilizing "uncontrolled" parameters (GONZÁLEZ-RODENAS et al., 2020). In addition, given the restrictions imposed by the NBA on full zone defense until the 2001-2002 season (RUIZ et al., 2014), and the ensuing three-second violation rule (which largely inhibits teams to play zone defense), detecting collective performance variables in defense appears to be a somewhat difficult task. Even so, we were able to identify a relatively fair number of synergies at the collective level during the analyzed match (see Figure 1).

Collective synergies were noticeably less frequent than dyads. This is an expected finding, since only one collective synergy can be formed during a play, whereas more than one dyadic synergy can be formed between two players in any given play. Collective synergies were significantly stronger in the first half in comparison to the second half of the match. One possible explanation for this finding may be related to the number of substitutes used during the second half, which is usually higher than in the first half (CROWTHER et al., 2017). The greater utilization of substitutes in the second half may have had an impact on the strength of collective synergies possibly due to the lower rapport between starting players and substitutes. Usually, players in the initial squad tend to have greater affinity with their starting teammates than with substitutes, as a result of the time spent playing together (SAMPAIO; DRINKWATER; LEITE, 2010).

Finally, only one dyadic synergy (D5; P2/P3) was positively correlated with the formation of collective synergies. Taking into account the nature of the measure (i.e., distance between the team centroid and the ball) analyzed for the identification of collective synergies, it is relevant to mention the typical defensive positions of the shooting guard and the small-forward (P2 and P3, respectively), who usually occupy positions in opposite sides of the court (KRAUSE; NELSON, 2019). Hence, when compensating for each other's displacements, players in these positions tend to contribute more decisively to moving the team's centroid towards the ball location. However, it is necessary to point out that the value of the explained variance (r^2) does not allow to infer that the D5 synergy is the main responsible for the variability observed in the distance between the team's centroid and the ball.

In summary, the measures proposed in the present study seem to appropriately portray the defensive synergistic behavior of basketball teams, both at dyadic and collective levels. Dyadic synergies predicated on the interpersonal distance between defenders were observed throughout the entire match. In addition, despite the fact that collective synergies were observed in only 30% (n = 21) of the plays, it is possible that the frequency of synergies predicated on this measure (i.e., distance between the team centroid and the ball) might be associated with more complex team defensive behaviors. Further research should be conducted to verify this hypothesis. Furthermore, we recommend that future studies employ additional measures at dyadic and collective levels, in order to identify other hierarchical synergistic traits in the behavior of sports teams.

PAPER 3

Multi-Level Interpersonal Synergies in Basketball: Comparing Two Teams in an NBA Match

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Highlights

- 1. For both teams, only a single dyadic synergy significantly contributed to the formation of synergies at the collective level.
- 2. The frequency and strength of synergies did not differ significantly between the teams.
- 3. Dyadic synergies were significantly more frequent than collective synergies.
- 4. Although the defensive performance of the teams could not be distinguished by synergistic behavior alone, the performance variables and task elements proposed here were able to capture a fair number of synergies at both levels (i.e., dyadic and collective).
- 5. It is possible that the utilization of alternative performance variables can uncover the synergistic characteristics of defensive performance.

Abstract

The purpose of this study was to compare the defensive interpersonal synergistic behavior of two teams during an NBA match, both at dyadic and collective levels. A competitive basketball match played by two NBA teams during the 2015/2016 regular season was analyzed. The Uncontrolled Manifold (UCM) concept was used to assess synergistic behavior at the dyadic (player-player) and collective (team-ball) levels. The task elements were players' positions captured by the bidimensional (x and y) coordinates. The performance goal for identifying the presence of dyadic interpersonal synergies was the interpersonal distance between defenders. At the collective level, the performance goal selected was the distance between the team centroid and the ball. The One-Way ANOVA and multiple t-tests were used to compare logUCM values between dyadic and collective levels, within and between teams, respectively. The chi-squared (χ^2) test was used to compare the frequencies of dyadic and collective synergies, within and between teams. In general, no significant differences were found in the frequency or strength of synergies within or between the teams. However, the variables proposed in this study were capable of identifying a fair number of interpersonal synergies at dyadic and collective levels.

Keywords: Basketball; interpersonal synergies; dyads; collective; uncontrolled manifold.

1. Introduction

Numerous human activities require people to constantly coordinate with others and to attune their individual goals with mutual collective goals (BUCHANAN; CORDOVA, 2022). This is even more meaningful in team sports, where shared functional goals (e.g., taking the ball as quickly as possible to the basket or the endzone) always outweighs individual goals (e.g., dribbling past an opponent instead of passing the ball to a teammate). Consequently, teammates need to coordinate with each other by acting as single unit in order to achieve their common performance goals. This coordination is attained through linking the (motor) degrees of freedom of two, or more, actors into synergies (BERNSTEIN, 1967; TURVEY, 2007). Synergies refer to the assembly of elements (e.g., muscles or players) that display covariation in the values of a certain variable with the purpose of stabilizing a performance goal (RILEY et al., 2011). In sports science literature, measures have been proposed to identify synergies at intra- and interpersonal scales (PASSOS et al., 2020; PASSOS; MILHO; BUTTON, 2018; ROBALO et al., 2021).

At the intrapersonal level, Gorniak et al. (2007a, 2007b) indicated, using a prehension task, a potential limitation in the ability of the central nervous system to organize synergies at two levels (i.e., two-finger within-a-hand and two-hand tasks). More specifically, the authors observed weaker strength in within-a-hand synergies during the performance of the two-hand task, while such synergies were stronger in the one-hand task (GORNIAK; ZATSIORSKY; LATASH, 2007a). Thus, as literature has pointed out that the same principles that govern intrapersonal coordination can be employed to understand coordination at the interpersonal level (SCHMIDT; RICHARDSON, 2008), it is fair to assume that synergies formed at the collective scale may potentially weaken those formed at lower levels. Indeed, the study by Montull et al. (2021) has shown that interpersonal synergies displayed dominance over intrapersonal synergies in a slackline dyadic task. Nevertheless, thus far, there are not, to the best of our knowledge, any studies addressing neither the analysis of interpersonal synergies at different levels nor the interdependence between these levels.

Team sports are a promising avenue of research on interactive human behavior (DAVIDS et al., 2006). Therefore, capturing multi-level interpersonal synergies in sports teams may provide relevant insights about these functional structures regarding the relationship between collective and dyadic or group scales (SANTOS; PASSOS, 2021). Accordingly, due to its features (e.g., lower number of players, shorter duration) the game of basketball can be considered an interesting model for identifying associations between synergy scales from the interpersonal standpoint (BOURBOUSSON; SÈVE; MCGARRY, 2010a, 2010b). More specifically, professional teams playing in the NBA (National Basketball Association) are arguably at the pinnacle of basketball competition and thus could provide information on the interpersonal behavior between players at the highest level of performance. Such a level of performance demands superior chemistry between team members, whereas capturing how this rapport was established may unearth the dyadic and collective synergistic behaviors from which team performance emerged. Hence, comparing the synergistic behaviors of these two teams in a match between them may help uncovering how interpersonal coupling tendencies relates to match performance both at the dyadic (i.e., player-player) and collective (i.e., whole team) levels (SANTOS; PASSOS, 2021).

With the purpose of identifying such synergistic traits, the Uncontrolled Manifold theory (UCM) has been employed as a means to capture two essential properties of interpersonal synergies: dimensional compression and reciprocal compensation (RILEY et al., 2011). Dimensional compression refers to the system's capacity to couple relatively independent degrees of freedom, so as to reduce the synergy's dimensionality, while reciprocal compensation is the ability of an element in a synergy to respond to variations in other elements (ARAÚJO; DAVIDS, 2016; SCHOLZ; SCHÖNER, 1999). Dimensional compression occurs when a lower dimensional variable is stabilized by the system's components through reciprocal compensation. In team sports (e.g., association football or soccer), the stability of relative phase modes have previously confirmed the presence of interpersonal synergies (DUARTE et al., 2013). However, the stable value observed by the authors, who employed a cluster phase method for this purpose, could not provide evidence that such stability occurred as a result of reciprocal compensation. Therefore, it seems plausible to maintain that the UCM concept is a viable means to verify whether a low dimensional variable (e.g., interpersonal distance between two defending teammates) has its value stabilized via reciprocal compensation (RILEY et al., 2011). This could provide relevant information with respect to basketball defense, since two defending players, for instance, constantly change the manner through which they interrelate in order to maintain their interpersonal distance within a certain range (PASSOS et al., 2020). Hence, by employing the UCM, one can assess which relevant performance goals – such as players' interpersonal distances – need to be stabilized, and which task elements (e.g., rate of change of players' positions on the court) vary to stabilize these relevant performance goals (PASSOS et al., 2022).

Indeed, the study of interpersonal synergies has been proposed as a means to uncover the way team sports players interact, and how this interactive behavior associates with performance in a given context. For instance, it can be hypothesized that basketball teams who excel in defense (i.e., by conceding fewer points than the opposition) during a match display superior degrees of reciprocal compensation in comparison to opponents who are less effective defensively (RILEY et al., 2011). Moreover, it is important to consider the different ways defensive performance can be analyzed. In basketball, defensive effectiveness may be a result of the efforts of two players (i.e., a dyad) guarding the ball carrier, and/or of a collective effort to ensure the whole team is organized and balanced in relation to the movement of the ball. Consequently, the proposition of performance variables that enable to identify synergistic behaviors at these levels (i.e., dyadic and collective) is likely to reveal the idiosyncrasies of the interactions between players that give rise to superior defensive performance. The interpersonal distance between two defenders and the distance between the team centroid (i.e., the average position of all defending players in a given moment) are two candidate performance variables at the dyadic and collective levels, respectively. Finally, resorting to the UCM concept could be a potentially expedient research approach to uncover the structure of the interactions that characterize defensive performance in basketball, as it enables to inform about the presence (or absence) and the strength of synergies, by working out how the variance of task elements stabilizes dyadic and collective performance variables.

Thus, the purpose of this study is to compare the defensive interpersonal synergistic behavior of two teams during an NBA match, both at dyadic and collective levels.

2. Methods

Data Acquisition

The data correspond to a competitive basketball match played by two NBA teams (referred to in this study as “Team A” and “Team B”) during the 2015/2016 regular season. The match score was 132 to 98 in favor of Team B. We chose this particular match due to its being played by teams regarded as two of the favorites to make it to the NBA Finals, as well as to the high scoring difference, which could, theoretically, facilitate the identification of any gaps in performance between the teams. Over this match, the teams under scope had 24 participating players (12 players from each team). Positional *x* and *y* coordinates were obtained through an optical tracking system (STATS SportVU, Stats Perform) (SPORTVU, 2022) with six cameras – mounted in the arena – that capture in real time the positions of the ball and the players within the court, with a sampling rate of 25Hz. Data are publicly available at the GitHub repository (https://github.com/linouk23/NBA-Player-Movements). Data were processed and visualized using Python 3.10.4 (Python Software Foundation), with Matplotlib 3.5.2 and Pandas 1.4.2 modules. Data was reconstructed in 2D, and the events selected for analysis were checked using images from the TV broadcast of the match. The analysis carried out on this study did not require identification of individual performers.

Players' positional roles were used to identify the dyads, according to the following criterion: P1 (point guard); P2 (shooting guard); P3 (small forward); P4 (power forward); P5 (center). Consequently, dyads were classified according to all possible interactions between players from each position (BOURBOUSSON; SÈVE; MCGARRY, 2010b): D1 (P1/P2); D2 (P1/P3); D3 (P1/P4); D4 (P1/P5); D5 (P2/P3); D6 (P2/P4); D7 (P2/P5); D8 (P3/P4); D9 (P3/P5) and D10 (P4/P5).

Categoric Variables

The teams involved in the match (i.e., Team A and Team B), as well as the hierarchical levels of the synergies (i.e., dyadic and collective) were the categoric variables of this study.

Synergy Analyses

The Uncontrolled Manifold (UCM) concept will be used to determine the limits of variability of values of task elements that allow to stabilize the performance measure. The purpose of UCM is to uncover the structure of variance of organisms with several degrees of freedom, controlled by a single measure (PASSOS; MILHO; BUTTON, 2018; SCHÖNER; SCHOLZ, 2007). The hypothesis that the selected task elements are really capable of stabilizing performance goals and, as such, of identifying an essential property of synergies (i.e., reciprocal compensation) can be verified through the ratio between compensated and uncompensated variances (BLACK; RILEY; MCCORD, 2007; RILEY et al., 2011). The UCM was calculated in time for each play, in both levels of analysis (i.e., dyadic and collective), considering their respective performance goals and task elements. The variance along UCM values over time uncovers the reciprocal compensation regarding players' movements – measured by changes in x and y coordinates – that stabilize the performance goals in each level around a given reference value, while the perpendicular variance reveals changes that were not compensated for by players' movements (PASSOS et al., 2020).

To calculate the UCM over time for each play, the model was discretized using discrete time points based on players' x and y positional coordinates. The length of each play was considered as the period between resets of the shot clock, which means either the start of a new play by the same team or a turnover in ball possession.

The task elements were players' positions captured by the bidimensional (x and y) coordinates. The performance goal selected for identifying the presence of interpersonal synergies in the defensive phase of play at the dyadic level was the interpersonal distance between defenders, which, it is assumed, tends to be stabilized to prevent an opponent to get near the basket (BOURBOUSSON; SÈVE; MCGARRY, 2010b). At the collective level, the performance goal selected was the distance between the team centroid – formed by the average positions of all players in the court – and the ball, whose stabilization is likely to ensure cohesion in defense.

The UCM output is a ratio between the compensated and the uncompensated variance, which means that there are synergies for whenever UCM ≥ 1. However, there is no upper limit for the UCM, thus, in order to reduce skewness of the distribution, a log transformation ($\log_{10}$) was applied to UCM values. Hence, synergies were classified as such when logUCM ≥ 0. Correspondingly, the higher the (positive) value of logUCM, the greater the strength of the synergy.

The UCM computation for synergy analyses was carried out using MatLab® 2022a (The MathWorks Inc., Natick, MA, USA).

Data Analysis

The One-Way ANOVA and multiple t-tests were used to compare logUCM values between dyadic and collective levels, within and between teams, respectively. The chi-squared (χ^2) test was used to verify differences in proportions regarding dyadic and collective synergies, throughout the match. Pearson's correlation (r) was used to verify the association between collective and dyadic synergies, in order to identify the dyads that significantly contribute to the formation of synergies at the team level. Explained variance (r^2) was calculated for significant correlations. Statistical procedures were carried out using SPSS, version 25. The significance level was set for $p < 0.05$.

3. Results

Multi-Level Synergies

Table 1 shows the mean values of logUCM, as well as the frequencies, of dyadic (D1 to D10) and collective (Centroid/Ball) synergies (logUCM ≥ 0) of Team A and Team B.

Table 3. Means (standard deviations) of logUCM and absolute (relative) frequencies of dyadic and collective synergies of Team A and Team B.

		Dyads										Collective
		D1	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**	**Centroid**
Team A	**logUCM**	0.90(0.63)	0.90(0.55)	0.89(0.57)	0.83(0.51)	0.90(0.56)	0.82(0.55)	0.89(0.52)	0.88(0.58)	0.82(0.51)	0.74(0.50)	0.65(0.57)
	Frequency	58(82%)	56(80%)	57(81%)	55(78%)	59(84%)	60(85%)	60(85%)	56(80%)	59(84%)	58(82%)	21(30%)*
Team B	**logUCM**	0.73(0.54)	0.76(0.47)	0.75(0.51)	0.82(0.53)	0.81(0.55)	0.78(0.46)	0.95(0.65)	0.70(0.50)	0.81(0.53)	0.77(0.51)	0.54(0.42)
	Frequency	63(82%)	63(82%)	66(86%)	68(89%)	61(80%)	66(86%)	64(84%)	60(79%)	65(85%)	64(84%)	25(32%)*

*Significant difference ($p < 0.05$).

It is possible to note that dyadic synergies were formed in most plays, whereas the number of collective synergies was substantially lower. Indeed, dyadic synergies were significantly more frequent than the synergies formed at the collective level, both for Team A ($\chi^2 = 23.11$; $p = 0.010$) and Team B ($\chi^2 = 23.73$; $p = 0.008$). In contrast, the One-Way ANOVA did not reveal any significant differences in the mean logUCM values between dyadic and collective synergies, either for Team A ($F = 0.739$; $p = 0.68$) or Team B ($F = 1.531$; $p = 0.12$).

Table 2 shows the values of Pearson's r for the correlations between collective and dyadic synergies (logUCM ≥ 0), for Teams A and B.

Table 4. Values of Pearson's correlation (*r*), significance and explained variance (r^2) between collective synergies and each dyad, for Team A (n = 21) and Team B (n = 25).

		D1	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
	r	0.32	0.29	0.13	0.17	0.46	0.43	0.11	0.34	0.30	0.27
Team A	**Sig.**	0.15	0.19	0.57	0.46	0.03*	0.05	0.61	0.12	0.17	0.23
	***r*²**	-	-	-	-	0.21	-	-	-	-	-
	r	-0.24	0.00	-0.14	-0.10	-0.03	-0.40	-0.19	-0.10	-0.04	0.13
Team B	**Sig.**	0.24	0.99	0.49	0.60	0.88	0.04*	0.35	0.61	0.81	0.51
	***r*²**	-	-	-	-	-	0.16	-	-	-	-

*Significant correlation ($p < 0.05$).

According to Table 2, for Team A, only D5 (P2/P3) was (positively) correlated with synergies at the collective level. More specifically, Team A's D5 dyad is likely to contribute approximately 21% ($r^2 = 0.21$) to the values of logUCM of collective synergies (formed between the defensive team centroid and the ball). On the other hand, results of Team B revealed that P6 (P2/P4) was negatively correlated with collective synergies. This dyad contributes around 16% ($r^2 = 0.16$) to the decrease in the values of logUCM of collective synergies.

Synergy Formation

Figure 1 displays the collective synergies captured during the match, within both halves, for Team A (top) and Team B (bottom).

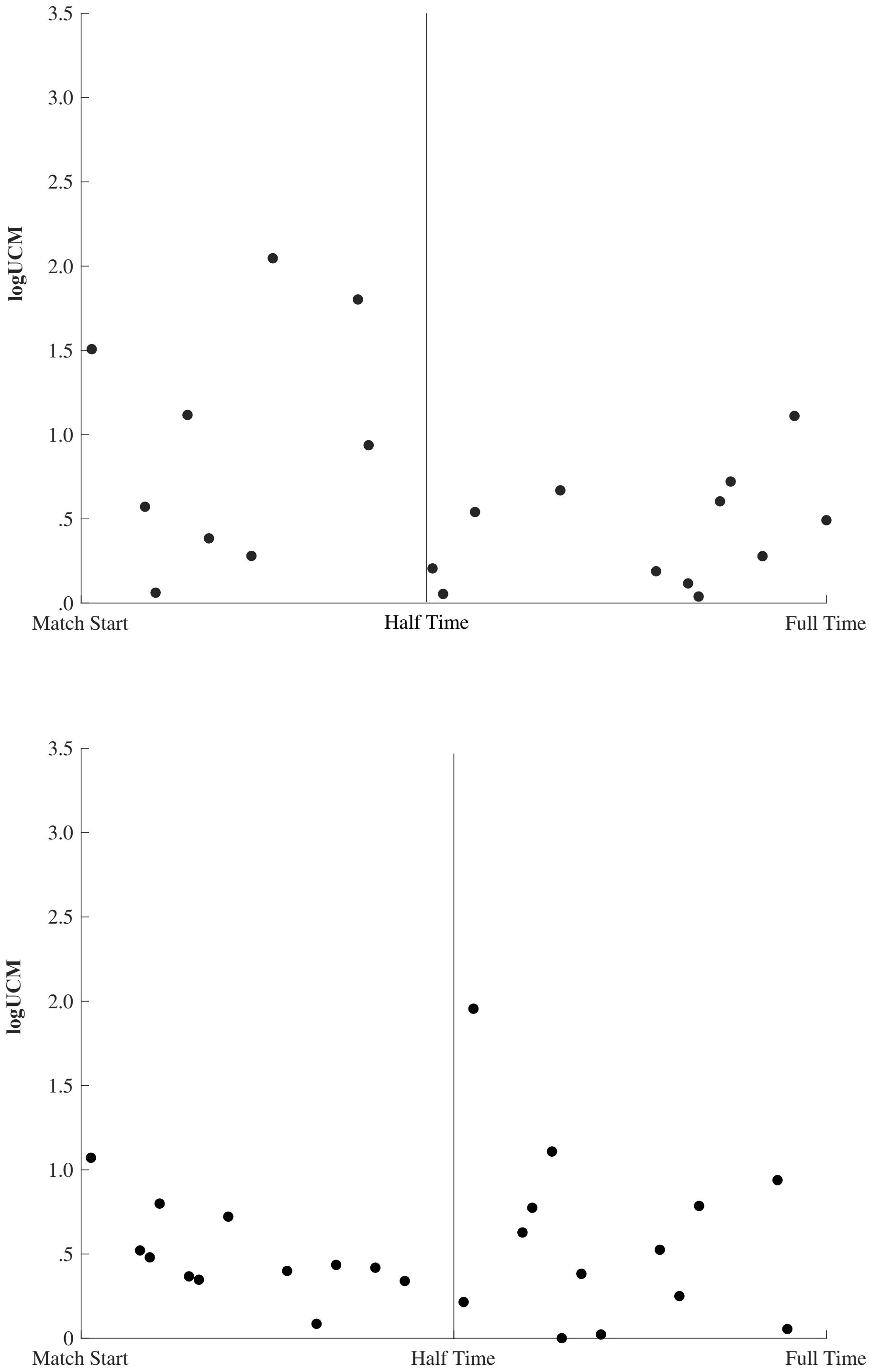

Figure 3. Collective synergies (logUCM ≥ 0) of Team A (top) and Team B (bottom) formed during the match.

The independent t-test showed significantly stronger collective synergies for Team A during the first half of the match, in comparison to the second half ($t = 2.395$; $p = 0.027$). Although more synergies were observed in the second ($n = 12$) than in the first half ($n = 9$), the difference was not significant ($\chi^2 = 0.429$; $p = 0.513$). On the other hand, no significant differences were found either for the strength ($t = 0.489$; $p = 0.630$) or frequencies ($\chi^2 = 0.360$; $p = 0.54$) of collective synergies of Team B between the first and second halves.

Figure 2 displays the dyadic synergies (D1 to D10) captured during the match, within both halves, for Team A (top) and Team B (bottom).

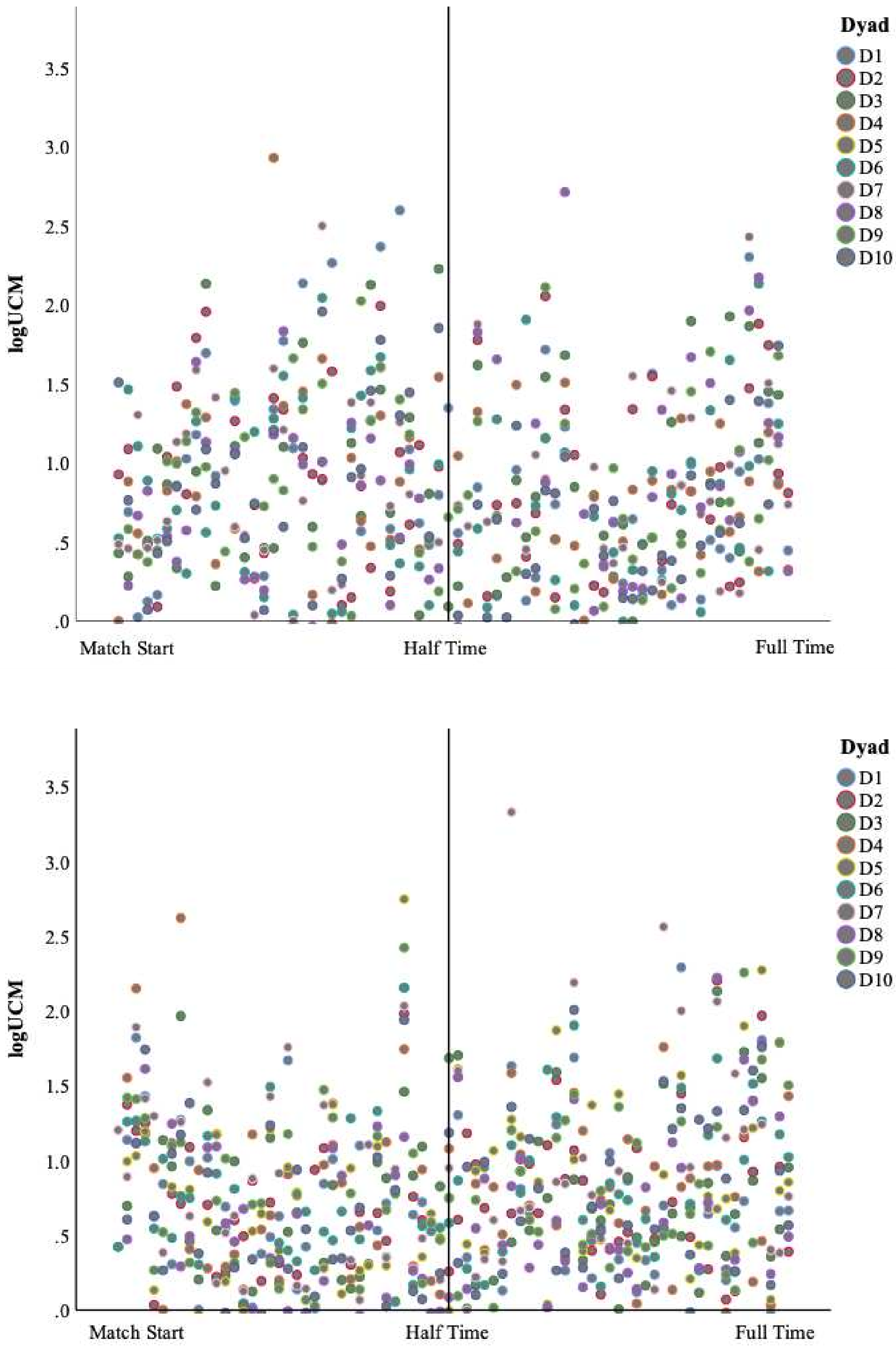

Figure 4. Dyadic synergies of Team A (top) and Team B (bottom) (logUCM ≥ 0) formed during the match.

No significant differences were found on the frequencies of any of the dyadic synergies (D1 to D10) of Team A, either between the first and second halves or across the entire match time ($\chi^2 = 0.478$; $p = 0.999$ and $\chi^2 = 1.403$; $p = 0.998$, respectively). Similarly, no significant differences were found among dyadic synergies between both halves nor during the entire match ($\chi^2 = 1.684$; $p = 0.996$ and $\chi^2 = 0.813$; $p = 0.999$, respectively). Also, results of the One-Way ANOVA did not reveal any significant differences in strength between the distinct dyads, either for Team A ($F = 0.511$; $p = 0.867$) or Team B ($F = 1.097$; $p = 0.363$).

Finally, no significant differences in strength (i.e., logUCM values) were found when comparing each dyadic (i.e., from D1 to D10) and collective synergy between both teams ($p > 0.05$).

4. Discussion

The purpose of this study was to compare the defensive interpersonal synergistic behavior of two teams during an NBA match, both at dyadic and collective levels. The main finding of this study is that, although the variables proposed were capable of capturing interpersonal synergies at the dyadic and collective, and for both teams, no significant differences were found in the frequency or strength of synergies between the teams. The only aspect that differentiated Team A and Team B regards the dyadic synergy (D5 and D6, respectively) that significantly contributed to the formation of synergies at the collective level.

These findings indicate that the synergistic behavior of both teams identified in this study may be a common feature across the entire league. Indeed, literature has pointed out that a mixed defense (i.e., zone and individual guarding applied concurrently) is the most usually employed defensive method, with a predilection for individual guarding/double-teaming (CSAPO et al., 2015). The evidence to corroborate this claim can be observed in our results, considering that defensive dyadic synergies were significantly more frequent than collective synergies. Actually, double-teaming (or “traps”) is a useful way for the defense to deal with top ball handlers in key areas of the court. This technique requires that two defenders position themselves “knee-to-knee” with each other, so as to force the ball handler to make a more complex pass (e.g., a lob or a bounce pass) or dribble move, thus improving defensive coverage and increasing the ball handler’s chances of turning the ball over (MEYER et al., 2022; WANG et al., 2018). In this regard, future research should increase the sample (i.e., investigate a higher number of matches) to verify whether the high frequency of defensive dyadic synergies is associated with increased effectiveness in double-team actions.

As for the association between dyadic and collective synergies, the fact that only one dyad significantly contributed to the formation of collective synergies in both teams is noteworthy. From the standpoint of specific defensive scenarios, this finding may also be related to actions of double-teaming performed by specific pairs of players. Indeed, double-teaming also demands cooperation from the other three teammates not directly involved in the action (KRAUSE; NELSON, 2019). This could imply that two defenders double-teaming a star player (ball handler) could also draw the attention of the whole defending team, thus making the rest of the defense (i.e., the other three defenders) compensate any variations in the movements of both the defenders directly involved in guarding the ball handler (KRAUSE; NELSON, 2019; WANG et al., 2018). Hence, considering that in the NBA defensive players often matchup with the same specific opponents, these particular dyads (i.e., D5, for Team A and D6, for Team B) could have been given the task of guarding the opposition's star player, which may have triggered the remaining defenders of both teams to join them in a coupled fashion, in order to reduce the space for the ball handler using his superior skills. Still, investigating specific matchups was outside the scope of our study, and further research is needed to confirm or refute this hypothesis.

Importantly, for Team A, stronger collective synergies were found during the first half of the match, when compared to the second half. This finding could be related to a potential onset of physical fatigue for Team A during the second half, which have been reported as a rather common fact during basketball matches, since studies have shown that players have reduced high-intensity activities and heart rate responses, in addition to increased low-intensity activities (BERKELMANS et al., 2018; STOJANOVIC et al., 2018). Accordingly, superior physical capacities are highly relevant for the formation of interpersonal synergies in basketball defense, as this process demands constant displacements from the players to compensate for variations in their teammates' movements. Also, as this difference was only found for Team A, it could be argued that Team B was physically better at maintaining defensive shape throughout the entire match (i.e., without variations between halves) than Team A, which could partially explain the difference in points scored during the match.

On the other hand, the frequency and strength of dyadic synergies did not differ between the teams. This finding may be of substantial relevance, since it can potentially indicate the hypothesis that the synergistic behavior predicated on the task element and performance goals employed in this study may be a common feature of NBA teams in general. If this is the case, it might be useful to investigate whether this is a characteristic that differs NBA teams from teams of lower leagues or age groups, therefore proposing a benchmark in terms of synergistic behavior at both dyadic and collective levels. Also, it is possible that the absence of difference in the frequency and strength of synergies between the teams is a result of the particular characteristics of the match analyzed, thus indicating that the formation of defensive synergies in basketball depends on the tactical and strategic aspects of each match and opposition. We recommend that future studies address these limitations, by analyzing synergistic behavior in matches played by different teams, and of different competitive levels and age groups.

Despite the aforementioned limitations of the present study, its relevance resides, essentially, on the fact that the task elements and performance variables proposed were capable of capturing defensive interpersonal synergies in basketball both at the dyadic and collective levels. Although the synergistic idiosyncrasies identified here could not, in general, distinguish both teams in terms of performance, they provide relevant insights, particularly with respect to the kind of task elements and performance variables that allow to determine how and which players interact on defense to try and stop the attacking team from creating scoring opportunities.

5. Conclusion

No significant differences were found in the frequency or strength of synergies between the teams. The dyadic synergies that most contributed to the formation of collective synergies (D5 and D6, respectively) was the only aspect that significantly distinguished the defensive behavior of Team A and Team B. Nevertheless, the variables proposed in this study were capable of identifying a fair number of interpersonal synergies at both levels (i.e., dyadic and collective). Even so, further research is needed to investigate other performance variables and their association with defensive performance. Also, alternative research methods can be employed to allow the analysis of a higher number of matches and teams.

GENERAL CONCLUSIONS

The study of the distinct levels of interpersonal synergies in team sports and the relationship between them, as well as of their hierarchical organization, can provide helpful information that researchers and coaches may apply to understand, plan, practice and assess players' interactive behavior and its association with team performance. However, investigating the multi-level and interdependent nature of the hierarchy of interpersonal synergies requires the identification of relevant task elements and performance goals. As new tasks are defined, some performance variables have their importance to synergy formation increased. Accordingly, identifying interpersonal synergies in team sports at different levels demands synergy formation to be regarded as a task-dependent phenomenon. Hence, we advocate that the characteristics of the tasks are the main constraints for the formation of synergies at all levels. As a result, we maintain that different performance goals should be employed for more consistently identifying synergies at different levels of analysis (e.g., dyadic and collective).

In order to conform to this claim, as well as to identify interpersonal synergies at the dyadic and collective levels in the defensive phase, we analyzed an NBA team during a regular-season match. Findings revealed that the measures proposed in the second paper within this thesis are appropriate to describe both the dyadic and collective defensive synergistic behavior of basketball teams. More specifically, we observed at least one dyadic synergy in each play, which means that the interpersonal distance between two defenders, regarded as a performance goal, was often stabilized by variations in the positions of these two defenders in the court (i.e., task element). Hence, the interpersonal distance between two defenders seems to be a reliable performance goal for identifying dyadic synergies in basketball. Also, results showed that a single dyadic synergy (D5) contributed around 21% ($r^2 = 0.21$) to the formation of synergies at the collective level. The typical defensive positions of the shooting guard (SG) and the small-forward (SF) (P2 and P3, respectively), who usually play defense in opposite sides of the court, may be a potential explanation for this finding, since, through the compensation for each other's displacements, players in these positions will be more likely contribute to shifting the team's defensive centroid towards the ball, as it moves. In addition, collective synergies were found in roughly 30% of the plays, indicating that the distance between the team defensive centroid and the ball (i.e., performance goal) was stabilized by defenders' displacements in 21 of the 70 plays under scrutiny. Taking into account the complexity of the formation of collective synergies, we consider that the latter number indicates that the performance goal was successful in capturing interpersonal synergies at the collective level.

Interestingly, when we compared the interpersonal synergies between two teams during an NBA match, no significant differences were found in the frequency or strength of synergies. Despite the fact that the proposed task elements and performance goals successfully captured dyadic and collective interpersonal synergies for both teams, overall defensive performance (i.e., the fact that one team conceded less points than the other) could not be predicated on differences in defensive synergistic behavior. However, it is possible that the synergistic behavior observed using these task element and performance goals may be a common characteristic across league teams. Stronger collective synergies were found for Team A in the first half of the match, in comparison with the second half. This finding may have relation to either the onset of fatigue for Team A in the second half or to the possibility that Team B was better at maintaining their defensive shape in comparison with Team A. Only one dyad of Team A (D5) and Team B (D6) was positively correlated with the formation of collective synergies, which could mean that both dyads were responsible for guarding the star player of the opposite team, consequently leading the remaining defenders to collectively compensate for their displacements, in order to stabilize the distance of the team's centroid to the ball.

Finally, the variables proposed in this study successfully identified interpersonal synergies at both levels (i.e., dyadic and collective). Notwithstanding, future research can propose other performance variables and verify their association with defensive performance, in addition to resorting to alternative methods to analyze multi-level interpersonal synergies.

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APPENDIX I

frontiers in Psychology

OPINION
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A Multi-Level Interdependent Hierarchy of Interpersonal Synergies in Team Sports: Theoretical Considerations

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INTRODUCTION

Most daily activities (e.g., dialoguing, road trafficking) entails constant coordination between humans. Interpersonal coordination may occur when people share similar goals (Schmidt and Richardson, 2008; Davis et al., 2016) and results from the haptic or visual perceptive coupling of relatively independent individuals (e.g., a figure skating duo, two competing tennis players), which temporarily form a single coherent unit, defined as a soft-assembled *interpersonal synergy* (Black et al., 2007; Riley et al., 2011). Synergies are the basic structures from which movement coordination emerges, as they provide individuals with proper means for dealing with complex behavior under countless circumstances (Kelso, 2021).

As in other movement systems, the identification of soft-assembled synergies in team sports is often grounded on two key properties: dimensional compression and reciprocal compensation (Riley et al., 2011). Dimensional compression refers to the process through which the coupling of the previously independent degrees of freedom (DoF) (e.g., players) within a system are reduced to a smaller number, resulting in a low-dimensional functional unit (Bingham, 1988; Riley et al., 2011). For instance, instead of describing the behavior of each individual element, it describes the behavior of a dyad composed by two coupled elements, which consequently decreases the DoF under analysis. In turn, reciprocal compensation describes the capacity of each player within a synergy to adjust their behavior (e.g., increase or decrease running velocity), to compensate the behavioral variability among teammates, in order to stabilize a performance variable (e.g., interpersonal distance) (Riley et al., 2011; Araújo and Davids, 2016).

In team sports, conceptualized as complex adaptive systems, it has already been suggested that interpersonal synergies are formed through feedback loops from the environment to the players and vice versa (Balagué et al., 2019). This suggests the existence of nested synergies, where some synergies are formed "within" others. A recent study investigating a cooperative dyadic slackline task displayed evidence of a nested organization between intrapersonal and interpersonal synergies, with the intrapersonal synergies at a lower level (i.e., formed within other higher-level synergies) of organization (Montull et al., 2021). Hence, attempts to identify interpersonal coordination patterns that account for performance outcomes should consider the specificities of (nested) synergy formation at the following levels of analysis: micro, dyadic level (e.g., among two teammates); meso, group level (e.g., intra-group) and; macro, collective level (e.g., intra-team) carried out through circular causality (Juarrero, 1999; Davids, 2015). Circular causality in dynamical systems was defined as a situation in which the cooperation among individual elements of a system influence the global system behavior, which, in turn, governs the behavior of these individual elements (Kelso, 1995). While the nested synergies concept implies a more fixed hierarchy, the idea of circular causality (not to be confused with hierarchy) suggests a more dynamic behavior of that hierarchy. For instance, in the course of a football match, sometimes synergies may be formed between two defenders (dyadic level) and influence the soft-assembling of synergies of an entire defensive sector, whereas at other times this meso-level of the defensive sector may influence how synergies between two defenders will be formed. That is why we suggest a "multi-level interdependent hierarchy" in the soft-assembling of interpersonal synergies.

The interdependence among these functional levels entails that only dimensional compression and reciprocal compensation may not suffice to accurately account for the principles that govern the formation of interpersonal synergies in team sports. Literature has recently proposed that degeneracy, defined as "the ability of elements that are structurally different to perform the same function or yield the same output" (Edelman and Gally 2001, p. 98), is likely a primary feature of soft-assembled synergies (Glazier and Davids, 2009; Araújo and Davids, 2016; Pol et al., 2020). In sports, these elements can be described as individual players, dyads or even groups of players. Therefore, there are several elements which are able to perform the same task/function, for instance if a full back fails to prevent an opposing winger from progressing toward the penalty area, another player (e.g., a center back) may be capable of fulfilling his/her role. In this paper, we suggest that these features allow to infer that coordination dynamics in team sports display task-specific hierarchies, which means that at every instant any of the three levels can "lead" the coordination dynamics within a team sports match.

Despite the growing interest on this topic, only recently has research raised awareness of the formation of interpersonal synergies in sports as a task-specific phenomenon with some kind of hierarchy (Balagué et al., 2019; Pol et al., 2020; Montull et al., 2021). This means that some important theoretical and methodological gaps regarding the hierarchical organization of interpersonal synergies in team sports still need to be bridged. Therefore, the purpose of this opinion article is to provide some theoretical considerations that support interpersonal synergies in team sports as task-specific phenomena with a multi-level interdependent hierarchical organization.

A MULTI-LEVEL INTERDEPENDENT HIERARCHY OF SYNERGIES IN TEAM SPORTS

In team sports, the ultimate purposes of a team during the course of match are to score points (or goals) and to prevent the opposition from scoring. These purposes induce teams to create scoring opportunities through coordinated movements, and to preserve defensive balance and organization (Gréhaigne et al., 1999). Consequently, acting in a coordinated and functional fashion enables players to deal with the continuously emerging goals (e.g., preventing an opponent from approaching a potentially risky area) that lead to scoring/avoiding points or goals (Araújo et al., 2015).

The dynamics of team sports performance imply that whenever an interpersonal synergy is unable to deal with contextual demands a "non-functional" synergy is assembled. Synergies are formed whenever coordination arises, although certain synergies may not fit the contextual demands, which will likely lead to performance decrements and/or unsuccessful outcomes. Therefore, players need to adapt to form new (and more functional) synergies, either to fulfill the ongoing task or in response to newly formed environmental constraints (Latash, 2008; Kelso, 2021). Accordingly, a specific performance goal (e.g., reducing the space, to decrease the opportunities of action of an opponent in possession of the ball) can be attained by the assembly of interpersonal synergies at distinct levels, such as dyadic or group levels (e.g., four players within a defensive set) (Balagué et al., 2019). By enabling different players to perform the same role (e.g., maintain an interpersonal distance to a teammate), degeneracy is an indispensable property to be accounted for in the analysis of synergistic behavior in team sports, since it allows reciprocal compensation and, consequently, dimensional compression (Araújo and Davids, 2016; Hristovski and Balagué, 2020). However, due to task constraints, players can switch roles from one moment to the next. For instance, in one moment a defender needs to stabilize the interpersonal distance to a teammate, in a dyadic behavior, with the purpose of preventing the player in possession to progress toward the goal, whereas in the next timestep she/he needs to stabilize the interpersonal distance to the closest teammates, so as to preserve a relative stability of the defensive line, in a group behavior with purposes that also include restraining the opponents' progression toward the goal. Interpersonal couplings at different levels interact with and overlap each other (e.g., the same player can contribute simultaneously to a dyadic and to a group synergy) to achieve specific performance goals (Montull et al., 2021). Therefore, since all the players within a team should be able to perform similar tasks (e.g., maintain a suitable interpersonal distance), degeneracy plays an essential role in the interdependence among levels of hierarchical organization of synergies. Nevertheless, the question regarding which synergy level "leads" the match dynamics remains unanswered.

Addressing such a complex issue requires summoning up the inherent principles of hierarchical synergic control, whether in multi-agent systems, such as team sports, or in less complex ones, such as human hands and fingers (Latash and Zatsiorsky, 2016). For example, after analyzing intrapersonal synergistic behavior in prehensile tasks, Gorniak et al. (2007a,b) identified the presence of idiosyncratic behaviors among synergies at two distinct hierarchical levels (i.e., hands level and fingers level) for producing force. Specifically, the authors observed that during prehensile tasks using only one hand, stabilization of the total force was achieved through the formation of strong synergies at the fingers level. Conversely, in prehensile tasks in which participants were asked to use their two hands, comparably strong synergies were formed between both hands, yet not between the fingers (Gorniak et al., 2007a,b). This suggests that the hands level (i.e., meso level) overlapped the fingers level (i.e., micro level) regarding synergy formation and strength at an intrapersonal scale. Thus, by hierarchical control we mean the existence (even if temporary) of a higher level, which constrains the behavior of elements at lower levels.

If interpersonal synergies conform to the same governing rules as those at the intrapersonal level (Riley et al., 2011), the aforementioned findings could precipitate the idea that soft-assembled interpersonal synergies involving more players result in the weakening of lower level synergies. For instance, a synergy formed between two center-backs "disappears" due to a new intra-sectorial synergy, formed by the whole defensive set. Nevertheless, a more likely explanation for the example above is that the lower level synergy formed by the two center-backs does not "disappear" but to keep the functionality, turns its focus to the stabilization of another performance variable, for instance from the interpersonal distance to the interpersonal angle, probably as a result of changes in task constraints (Fajen, 2005; Balagué et al., 2019). In fact, changing task characteristics may lead to a reorganization of the hierarchical levels of a synergy, so that the levels with higher functionality to achieve a specific performance goal are prioritized. For instance, two players forming a dyadic (micro-level) synergy aiming to regain ball possession can subsequently give up on their initial task goal, yet preserve the synergy while directing the focus to how to reestablish the balance of the whole defensive sector – a meso-level synergy (Bingham, 1988).

New task definitions emerge as a result of match dynamics, and consequently some performance variables can become more relevant to synergy formation. Performance variables characterize the performance goals that players seek to stabilize together (e.g., interpersonal distances or angles). Thus, it seems appropriate to suggest that the hierarchical organization of synergies is more closely related to these "new" performance variables, than to the number of players involved *per se*. If so, it will be up to the task characteristics to determine the hierarchical organization of synergies. Therefore, we hypothesized that the formation of functional (i.e., successful) interpersonal synergies in team sports is governed by a task-specific, multi-level interdependent hierarchy. To deal with this sort of hierarchy, degeneracy plays a relevant role. A system in which all the structurally different elements (i.e., players) are able to perform the same role (e.g., stabilize interpersonal distances or angles) are more likely to have the necessary conditions to adapt and achieve the same outcome by assembling synergies to successfully perform tasks at all levels.

Preliminary findings in soccer (association football), reported by Carrilho et al. (2020), revealed that synergies formed by different numbers of players generated distinct values of the performance variable (team synchronization). The authors investigated two opposing teams during a match, and compared synchronization values between different team configurations (i.e., groups of players), assuming these configurations as different synergistic levels. Although only initial humble steps have been taken in this direction, the current empirical evidence has thus far reinforced the essential role of degeneracy in addressing a multi-level interdependent hierarchy of interpersonal synergies in team sports.

Thus, we suggest that addressing the issue of a multi-level interdependent hierarchy of interpersonal synergies requires identifying the most relevant performance goals for the three levels of analysis (i.e., micro, meso, and macro) and for every phase of play in a team sports match. Some examples of relevant performance variables include players' interpersonal distance within a dyad (the micro level), the area of a polygon created by the players within a group (the meso level) and the distance between a team's centroid and the goal (the macro level). These variables can be measured using players' positional data allowing to capture interpersonal synergies for the three levels of analysis (please see Passos et al., 2018 for further detail). As for how to capture the interdependencies among synergy levels, despite being a tad early to define a method for this purpose, we suggest that addressing this issue by using a cluster analysis might be a promising start, as Montull et al. (2021) have already ascertained in their study with an interpersonal slackline task. However, the key issue is: How to measure the relevance of a performance variable? This issue remains unresolved!

DISCUSSION

The aim of this opinion article was to evoke key assumptions supporting the hypothesis of interpersonal synergies as a multi-level, interdependent, hierarchically organized phenomena, as well as to discuss their implications for studying multi-level synergistic behavior in team sports. Here we may suggest that task-specificity constrains the formation of synergies at all levels. Accordingly, identifying the hierarchical organization of interpersonal synergies in team sports entails the adoption of a perspective of synergy formation as a task-dependent phenomenon. However, what needs to be discussed is, how do task characteristics prioritize certain levels over others? Do stronger synergies constrain (overlap) weaker synergies, or are the levels defined by the number of elements that assemble a synergy? All these questions remain unanswered. Previous research in football (Carrilho et al., 2020) provided us with some thought-provoking queries, regarding the role played by performance goals in synergy formation and strength at each level, as mentioned throughout this paper. Therefore, we suggest that future attempts to address these questions should be equated with the relevance of the performance goals.

Finally, investigating the hierarchical organization of synergies in team sports, as well as the relationship among the distinct synergistic levels may help researchers and coaches in understanding, planning, practicing and assessing team performance, as well as the effectiveness of styles of play.

AUTHOR CONTRIBUTIONS

RS and PP: article development and composition. PP: final draft review. All authors contributed to the article and approved the submitted version.

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